Water Resources of the Upper Rio Grande Basin: History, Hydrology and Management

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The Rio Grande stretches 1885 miles from its headwaters in the San Juan Mountains of southern Colorado to the Gulf of Mexico. Along the way it crosses the states of Colorado, New Mexico and Texas, and it forms the border between Texas and the Estados Unidos Mexicanos, or Mexico. This paper reviews the water resources of the Upper Rio Grande Basin, a catchment that extends from the headwaters to Fort Quitman, Texas which is about 100 miles downstream from the metropolitan complex of El Paso/Juarez (Figure 1). The Upper Rio Grande Basin makes a natural unit for analysis because it is a more or less closed system politically and hydrologically. Politically, it is the region covered by the Rio Grande Compact among the basin states and by the 1906 Treaty between the United States and Mexico. Both agreements allocate the waters of the upper basin independent of the lower basin. This is physically possible because essentially all of the water resources of the Upper Rio Grande Basin are consumed in the upper basin itself; the river is almost dry downstream of Fort Quitman until it is replenished by the Rio Conchas.

The Upper Rio Grande is a typical example of river basins in semi-arid environments. The water resources of the basin include both surface and groundwater. River flows are maintained mostly by seasonal precipitation. Spring snowmelt and summer monsoon storms are the main sources of surface flows and for groundwater recharge. Summer storms are highly localized, while snowmelt is the result of winter frontal storms, primarily over the San Juan Mountains in southern Colorado. Relations between surface and groundwater are locally complex, but in general the reach of the river above Santa Fe, New Mexico is gaining while it is losing further south.

The Upper Rio Grande illustrates the extreme challenges posed by management of a river basin in the arid West. The basin provides water for flora, fauna, agriculture, domestic

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consumption, recreation, business and industry. The basin's water balance depends on complex interactions among:

- Regional and local climate
- Runoff
- Evapo-transpiration
- Groundwater
- Stream flow
- Multiple human uses

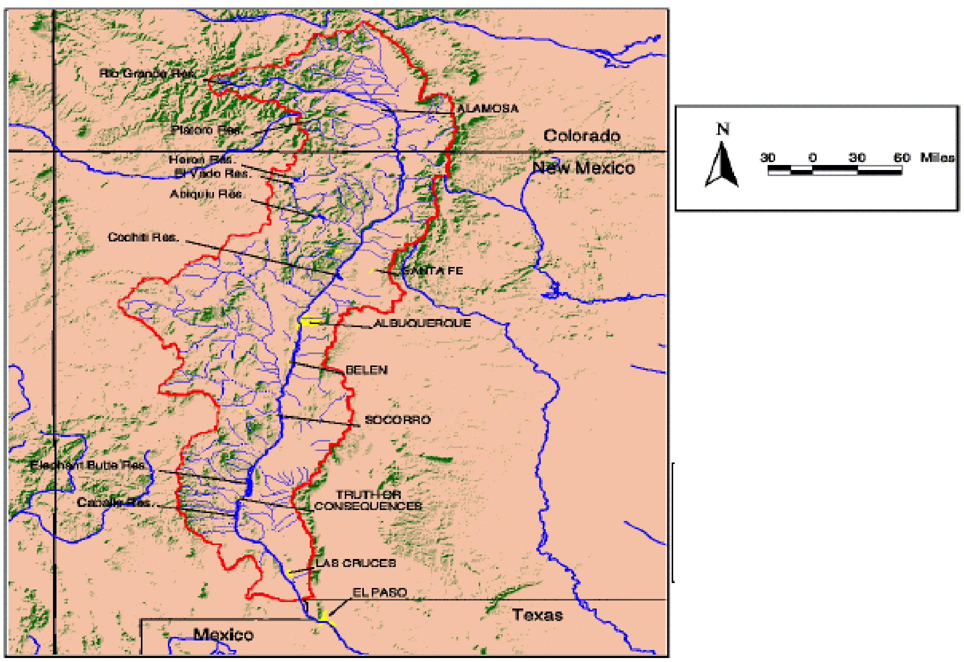

Figure 1. The Upper Rio Grande Basin

These components vary enormously in space and time. Furthermore small changes in some components of the basin's water balance may result in large changes in others. Increasing demands from competing uses may eventually deplete groundwater resources, alter the allocation of surface water resources, and affect water quality. Global climate variability may further alter the water balance by modifying the regional hydrologic cycle.

To provide background for the U.S. – China Workshop on Water Resources, we outline the history of the Upper Rio Grande Basin, its physical setting and its management in this white paper. We concentrate on management of the water resource, especially management related to

- Forestry and agriculture

- Ecology
- Industrial wastewater
- Floods and drought

We describe legal and institutional mechanisms that have been developed for managing conflicts among competing demands; we review science and technology available for mediating conflicts and managing the river; and we conclude with a list of issues facing river managers and policy-makers.

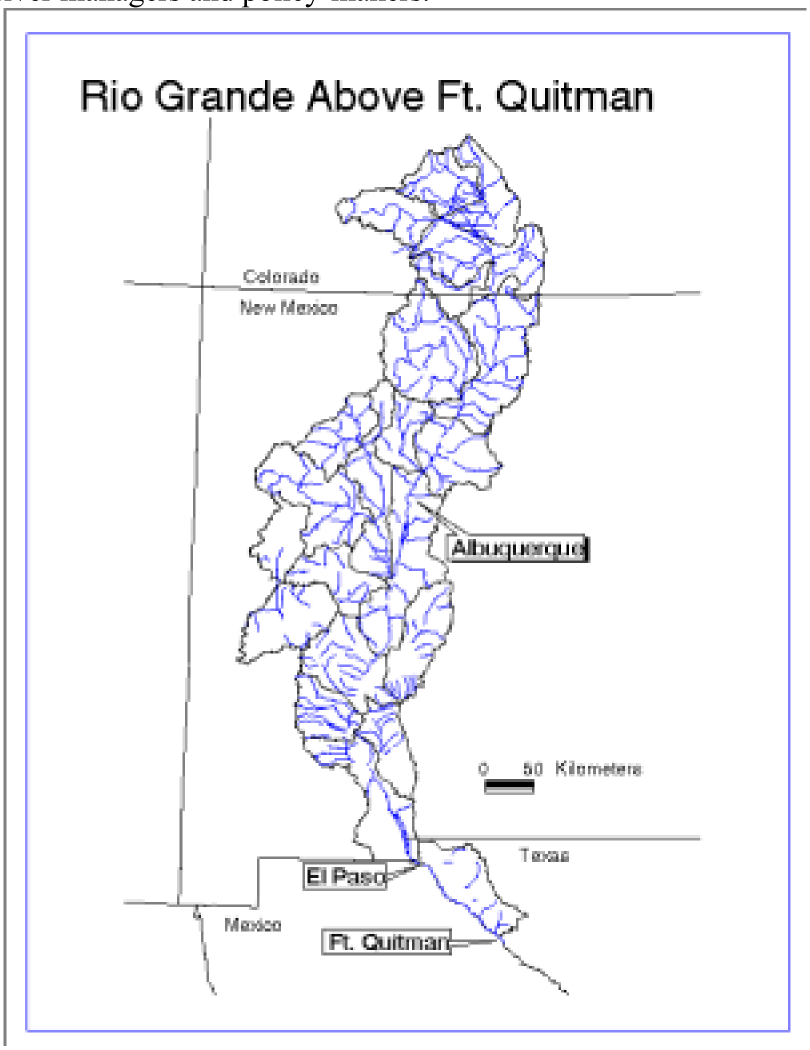

Figure 2. Major Stream Network

Physical Setting

The Upper Rio Grande basin lies between the headwaters of the Rio Grande in the San Juan Mountains of Colorado and Fort Quitman, Texas (Figure 2). The upper basin covers approximately 36,000 mi^2 (92,000 km^2) in southern Colorado, New Mexico and west Texas. It is bounded on the west by the United States Continental Divide and on the east by the Sangre de Cristo Mountain Range and a series of smaller ranges running generally north-south through the state of New Mexico. Elevations range from over 14,000 feet. (4267 m) to less than 4,000 feet (1219 m). The mainstem of the upper Rio Grande is about 725 miles (1160 km) long. The river is approximately 175 miles (280 km) long in Colorado, 450 miles (720 km) long in New Mexico, and 100 miles (160 km) long in Texas. From north to south the river's major tributaries are the Conejos River, the Rio Chama, Galisteo Creek, the Jemez River, the Rio Puerco, and the Rio Salado. Additionally, 96,000 acre-feet (118.5 x 10^6 m^3) per year are obtained from the Colorado River Basin through the San Juan-Chama Diversion.

The Basin has a semiarid climate common to the rest of the Southwestern United States. Approximately 98% of the precipitation evaporates (Figure 3). Mean annual precipitation ranges from greater than 50 inches (127 cm) per year in the Colorado mountains to less than 6 inches (15 cm) per year south of Albuquerque.

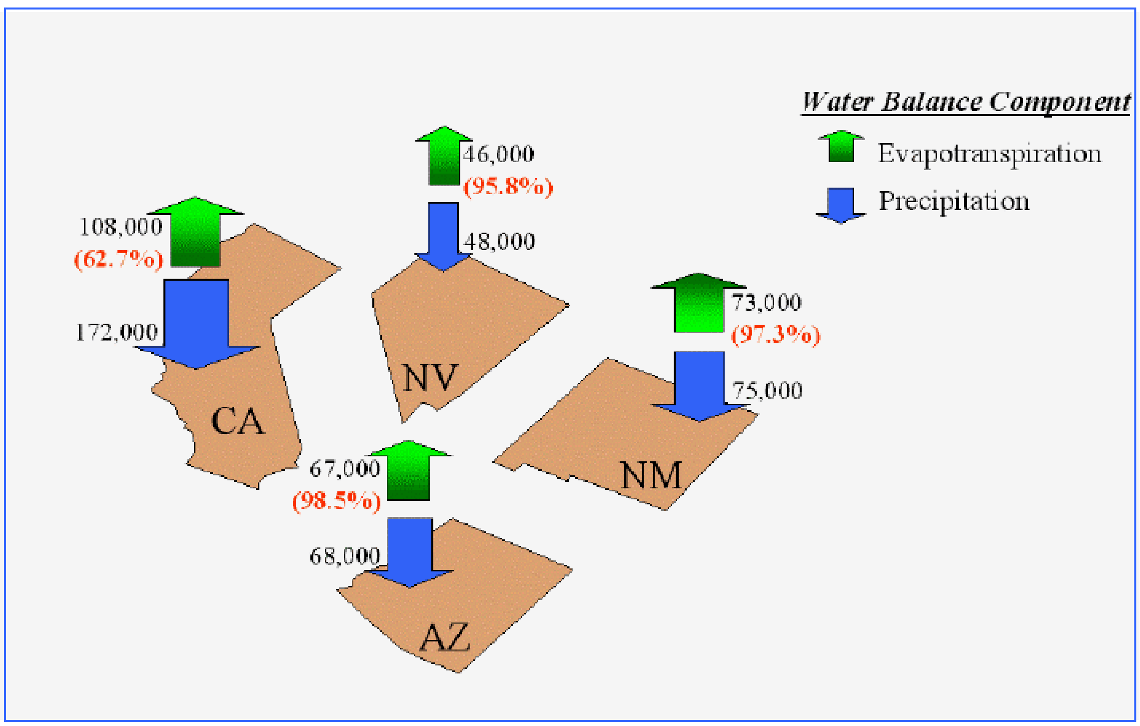

Figure 3. Balance of Evaporation-Precipitation in the Southwest *(Data in millions of gallons/day. Source, USGS Water Use Report, 1990)*

Precipitation shows the typical bimodal pattern of the Southwest: large-scale frontal precipitation during the winter and localized convective storms associated with the North American monsoon in the summer. There is considerable variation with elevation (Table 1). Higher elevations receive much more precipitation than lower (Figure 4), and high elevation precipitation generally comes in the form of winter snow; lower elevations are likely to receive most of their precipitation as summer rain (Figure5). Precipitation values for Figure 5 have been normalized for purposes of comparison by the given station's maximum monthly average.

Table 1 -- Average Annual Precipitation for Selected Sites in the Upper Rio Grande Basin				
Name	State	Location	Elevation (feet)	Average Precipitation (inches)
Wolf Creek Pass	Colorado	San Juan Mountains	10,641	45.0
Taos	New Mexico	Northern NM	6,990	12.5
Albuquerque	New Mexico	Central NM	5,310	8.7
Hatch	New Mexico	Southern NM	4,040	9.8
El Paso	Texas	Western TX	3,760	7.8

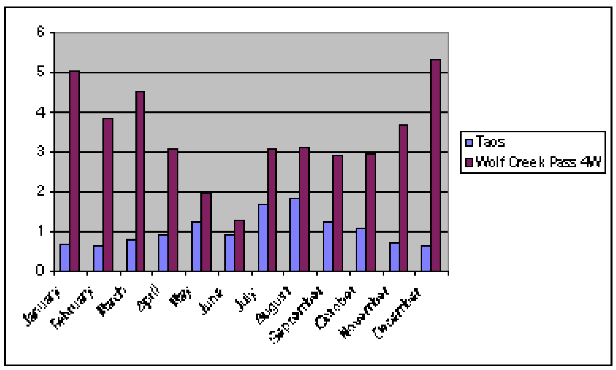

Figure 4. Elevation Contrast between Precipitation *(Source: Western Regional Climate Data Center)*

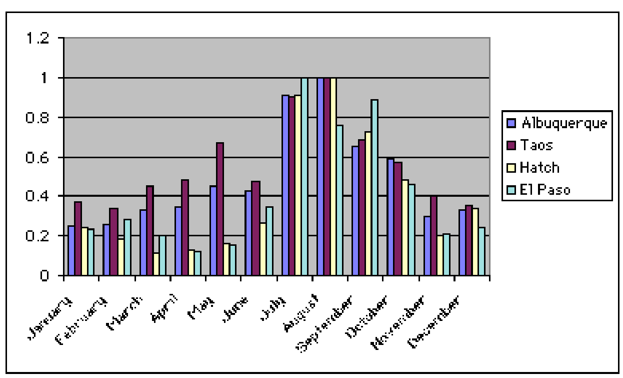

Figure 5. North-South Comparison of Normalized Precipitation *(Source: Western Regional Climate Data Center*

Winter precipitation dominates flows in the northern basin while summer storms are more important in the south. Hence, flow is seasonal with a large peak in May-June due to snowmelt and other peaks in the July-August timeframe. Furthermore, there is a strong North-South trend with northern gages showing large spring peaks and southern showing greater summer effects. (Figure 6).

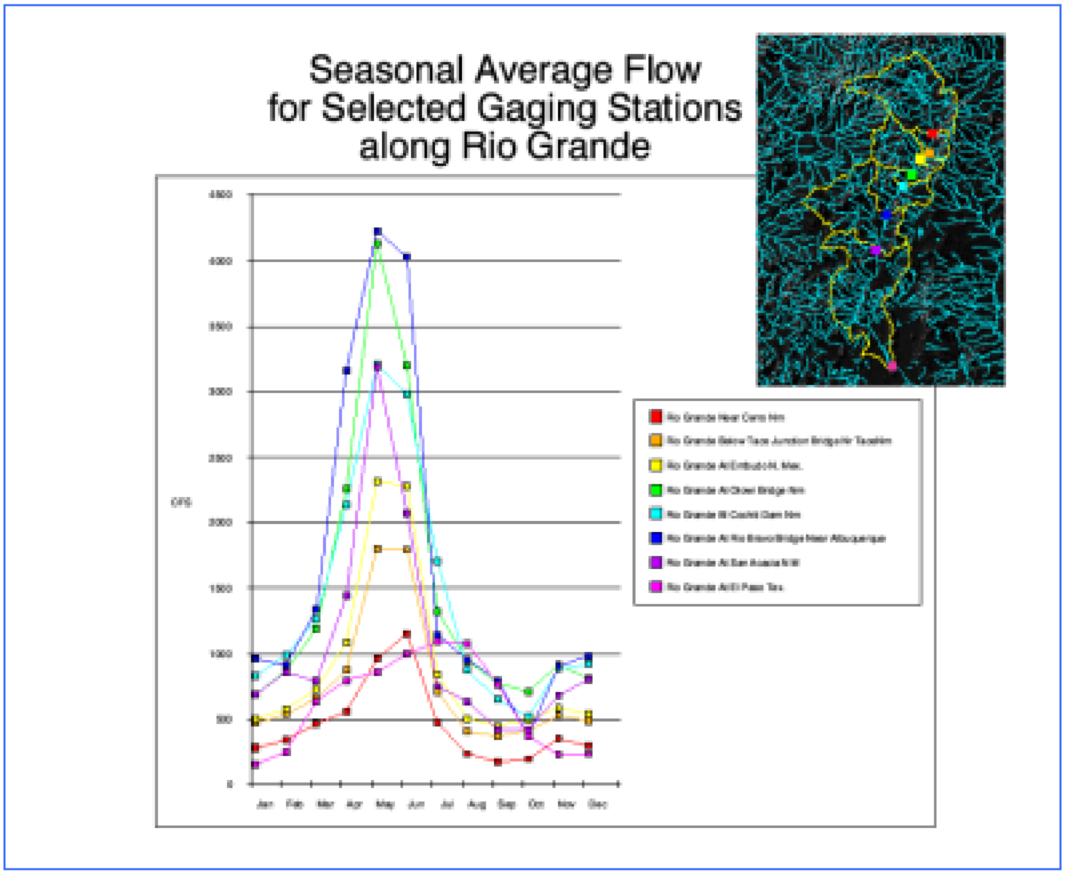

Figure 6. Mainstem Hydrographs *(Source: US Geological Survey)*

Seasonal flow percentages of unregulated tributaries of the Rio Grande show the same North-South gradient. Spring flows (April-June) attributable to snowmelt contribute much more to overall flow in the north while summer flows (July-September) associated with convective monsoon storms are most important in the south (Figure 7).

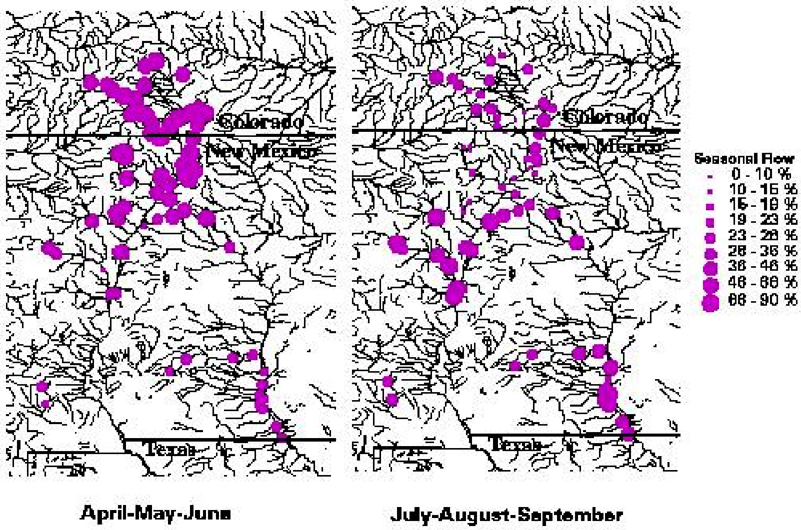

Figure 7. Seasonal Flow Percentage Unregulated Tributaries of the Rio Grande and Pecos Rivers *(Source: USGS)*

Total annual stream flows in the upper Rio Grande are strongly affected 1) by irrigation which begins in the San Luis Valley of Colorado and continues the length of the river and 2) by the contributions of tributaries, especially the Rio Chama. Thus, there is considerable variation in average flows along the mainstem (Table 2). Furthermore, annual flow is highly variable. For instance, annual flow varied from a low of 215,200 acre-feet (266 x 10^6 m^3) to a high of 1,102,200 acre-feet (1360 x 10^6 m^3) at Del Norte between 1890 and 1987.

Table 2. Average Annual Flow in Upper Rio Grande Mainstem 1890-1987

Gage	Location	Flow (acre-feet)
Del Norte	Above San Luis Valley	660,000
Lobatos	Below San Luis Valley	315,000
Otowi	Below Rio Chama	1,100,000
San Marcial	Below Middle Rio Grande Valley	745,000

Major aquifers are the Espanola Basin north of Santa Fe, the Albuquerque Basin, the Mesilla Bolson and the Hueco Bolson. Groundwater provides most of the drinking water, while surface water is used primarily for agriculture. Surface water quality deteriorates from the headwaters to the El Paso Basin because of agricultural pollution and evaporation.

History

The "Law of the River", far from being established and well-defined, is currently in flux, and many issues will no doubt be resolved in court. In particular, the claims of Native Americans have so far been largely ignored. The need to provide water to preserve endangered species was not recognized at the time many agreements were concluded.

Native American irrigation systems initiated use of the upper basin's water resources. Under Spanish rule (1500-1821) water was held in common for all inhabitants by the viceroy of New Spain. Irrigation water was distributed to colonists on the advice of municipal councils. This gave rise to the *acequia* system of communal ditch irrigation in the northern valleys of New Mexico. The acequia system, still in effect today, is now governed by state law. New Mexico has approximately 800 community acequia associations serving farms that range from 1 to 500 acres (0.4 – 200 ha) in size with the majority under 20 acres (8 ha).

The modern era of large-scale water development started between 1870 and 1890 when irrigated acreage in the San Luis Valley increased from some 6,000 (2,400) to more than 300,000 acres (120,000 ha). Soon water shortages occurred in New Mexico, the El Paso area, and Mexico. Mexico lodged a formal complaint with the United States. The United States initially responded with the Harmon Doctrine in 1895 which held that the United States was not obliged to deliver water downstream to Mexico. However, the Harmon Doctrine was eventually superseded by the 1906 Water Treaty with Mexico, which commits the United States to deliver the first 60,000 acre-feet (74 x 10^6 m^3) of water from the Upper Rio Grande to Mexico at the heading of the Acequia Madre, located at the so-called International Dam, near downtown El Paso, Texas. The treaty is the most powerful commitment on the river and its implementation through the International Boundary and Water Commission forms a vital part of any long-term solution to the problems of water scarcity in the region. Although the treaty provides for a "sharing of shortages", this phrase is undefined. In times of shortage it may be necessary to develop additional rules for water exchanges, conjunctive management of surface and groundwater and even storage. The position of the Mexican government is that no upstream pumping of groundwater can affect the quantity of water delivered to it. The Rio Grande Rectification Convention attempted to resolve some of these issues in 1933.

The Reclamation Act of 1902 authorized construction of Federal irrigation projects in the western United States. It is important to note, however, that the projects themselves are governed by state water laws. The U.S. Congress authorized construction of the Elephant Butte Reservoir in southern New Mexico in 1905. The reservoir, which can store up to 2.1 million acre feet (2591 x 10^6 m^3) of water, was completed in 1916. In 1909, Colorado secured permission from the U.S. to build several private reservoirs with the aggregate capacity of about 300,000 (370 x 10^6 m^3)acre-feet. The initial stages of the flood control system below Elephant Butte Reservoir were constructed in 1933. The present-day system, including Caballo Dam, protects both the Mesilla and El Paso/Juarez valleys, while providing the irrigation system for the valleys.

By 1923, contention among Colorado, New Mexico and Texas required intervention by the U.S. Government. Congress consented to negotiation of the Rio Grande Compact among the states and the Federal Government, and in 1938 the Compact was signed. This was the beginning of the Law of the River. It provides for a commission with four members – one from each state and another from the federal government – to oversee allocation of the water. Elephant Butte Reservoir in southern New Mexico is the final delivery point for the waters of this compact. Essentially the Compact insures that an average of 750,000 acre-feet (925 x 10^6 m^3) of water per year will reach Elephant Butte Reservoir. From this storage, about 620,000 acre-feet (765 10^6 m^3) on average are released annually for down stream use in the El Paso/Juarez region. However, the Compact divides the water among the three states on a sliding formula, depending on the available water each year; it apportions low-flow years according to a series of formulas based on flow at the U.S. Geological Survey gage at Otowi Bridge in northern New Mexico. Since it is the responsibility of New Mexico to deliver a certain quantity of water at Elephant Butte Reservoir, New Mexico must bear the carriage loss (due primarily to evaporation, transpiration and infiltration) between the Otowi gage and Elephant Butte.

A number of lawsuits have resulted from the compact because the priority of water rights below Elephant Butte is unclear. Both New Mexico and Texas have filed suits to determine the ownership of the water put to beneficial use by irrigators in the area. This litigation has in turn generated strong legal responses from other entities with a stake in compact waters. For example, the Bureau of Reclamation has asserted that it owns the water rights for the entire project. Therefore, any future use of the water for non-agricultural purposes would require that it act as broker of the water. The Elephant Butte Irrigation District claims to hold legal title to the water for the benefit of its agricultural members and to be responsible for brokering water for non-agriculture uses as the agent of its members. On the other hand, the individual farmers argue that the water rights belong to them as beneficial users. Since the federal project has been paid out, they claim to be free to transfer and sell the rights to whomever they choose. They would receive the economic benefits from such sales as individuals. This would create a private market for water rights similar to that which exists elsewhere in New Mexico.

The Middle Rio Grande Conservancy District (MRGCD) was created north and south of Albuquerque, New Mexico in 1925. It is a political subdivision of the State of New Mexico with all the powers of a public or municipal corporation. Its responsibilities are providing and maintaining flood protection and drainage; and maintenance of ditches, canals, and distribution systems for irrigation. Its boundaries extend north to Cochiti Dam (Figure 1) and south to the north boundary line of the Bosque del Apache National Wildlife Refuge. Voters must own property within the benefited area of district. A Board of Directors, elected for 4 year terms, represents constituents from 4 counties and has one member at large. El Vado Dam (Figure 1) was completed as part of the MRGCD irrigation, drainage, and flood control development in 1935. Deliveries of the waters of the Middle Rio Grande Project started with the storing of irrigation water after the completion of El Vado Dam.

While most federal environmental laws do not in themselves allocate a portion of water to the environment or to federal agencies, there is no doubt that federal agencies, especially the Fish and Wildlife Service and the Environmental Protection Agency, will play a vital role in regulating the quantity and quality of water in the river. Three major environmental laws will figure in any long-term solution for providing water to the region on a sustainable basis. These are the Endangered Species Act, the Clean Water Act and the National Environmental Policy Act. Additional authorizations affecting the operations of water management in the entire Rio Grande Basin include the National Wild and Scenic Rivers Act and the Fish and Wildlife Coordination Act. In addition, Native American Pueblos have perhaps the most senior claim on the river, and they have recently begun to act on those claims.

Regional Development

The Upper Rio Grande Basin is changing dramatically as its population grows and its economy shifts from an agricultural base to manufacturing and service. The semi-arid Southwest is the fastest growing region in the United States. The combined population of California, New Mexico, Utah, Arizona, Nevada, and Colorado is expected to grow from 45 million today to 64 million in 2030. Among individual states, growth rates in New Mexico, Utah, Arizona, and Nevada are the highest in the United States and Colorado is growing nearly as fast (Figure 8).

The major cities along the corridor of the Upper Rio Grande are, from north to south,

- Santa Fe, New Mexico. Approximate metropolitan area population of 100,000
- Albuquerque, New Mexico. Approximate metropolitan area population of 500,000
- Las Cruces, New Mexico. Approximate metropolitan area population of 100,000
- El Paso, Texas. Approximate metropolitan area population of 600,000
- Juarez, Chihuahua State, Mexico. Approximate metropolitan area population of 900,000

The twin cities of El Paso/Juarez are expected to grow to about 2,000,000 in 2010. The cities along the upper corridor were each smaller than 20,000 in 1906 when waters of the Rio Grande were first allocated between Mexico and the United States. Increasingly, 19th century water allocation strategies are proving inadequate for the realities of the turn of the 20th century on both sides of the border. Municipal and industrial uses of water, largely ignored in 1906, are now the major worry.

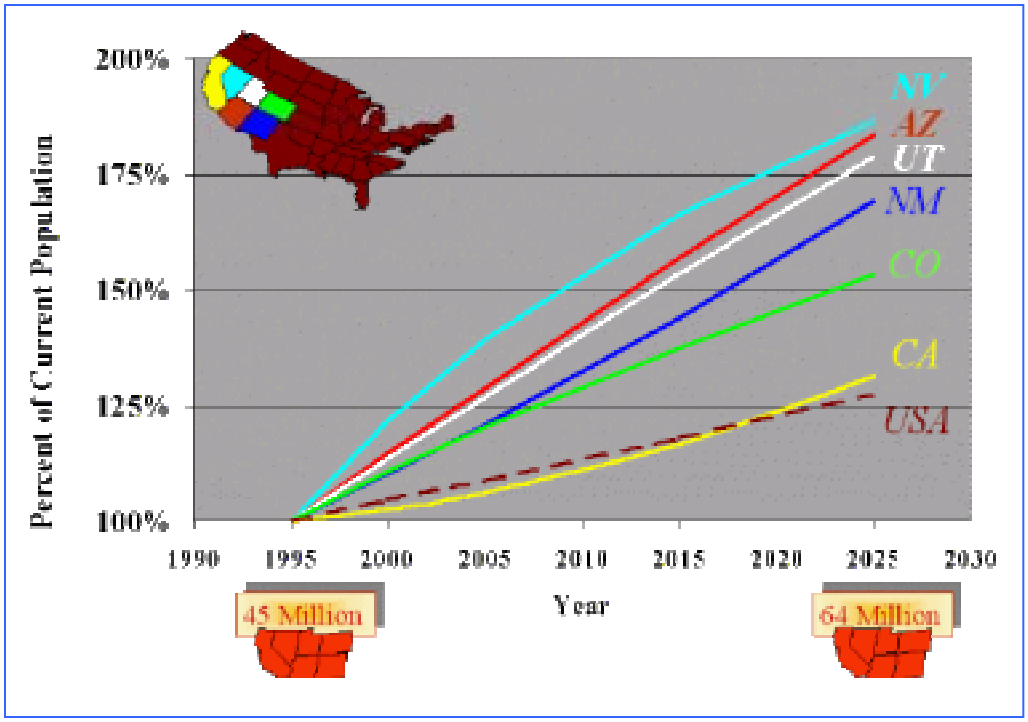

Figure 8. Projected Growth in the Western U.S.

Agricultural and Forest Resources

Historically, water development in the western United States was undertaken to enable agricultural use and electrical power generation. This region has a minuscule amount of hydropower, and infrastructure investment has historically been directed towards agriculture. Agriculture in the western United States is far more dependent on irrigation than in the eastern United States.

The Upper Rio Grande Basin epitomizes traditional divisions of water in the western United States: about 87% of the water in the region is consumed by agriculture. (Figure 9).

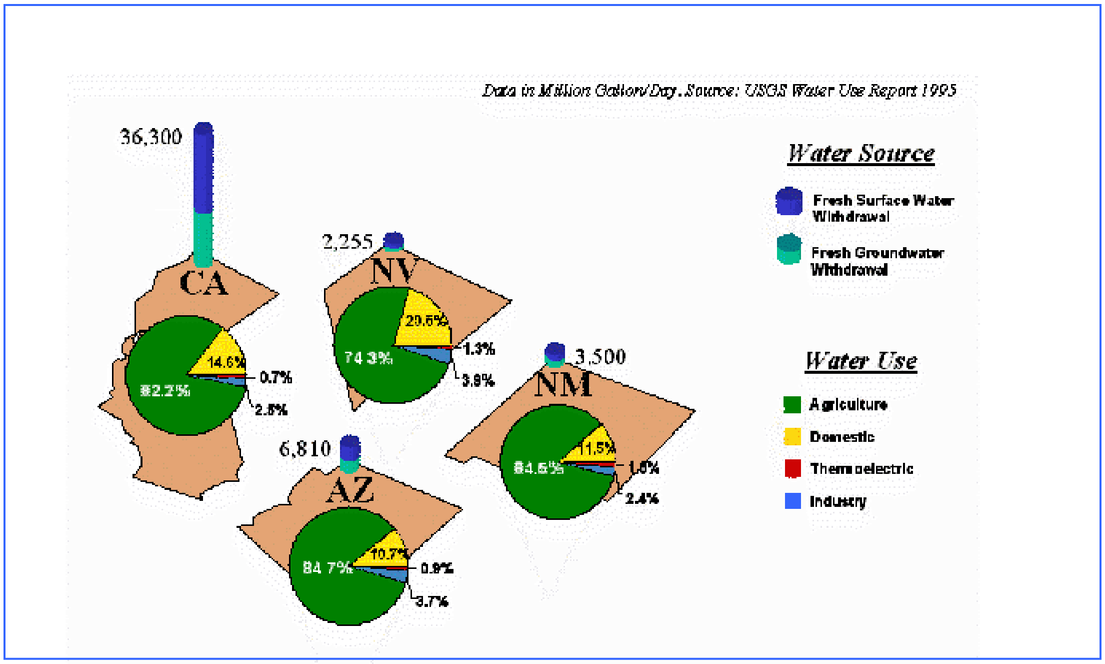

Figure 9. Distribution of Water Among Uses

The distribution of water does not reflect current economic or demographic trends. About 2% of all employment in the region and 1-2% of total income is derived from agriculture and forestry. In New Mexico, for instance, agriculture, forestry and fisheries accounted for 1.8% of the Gross State Product in 1996 (Figure 10). Major crops produced are hay, cotton, onions, chili peppers, and potatoes (Figure 11).

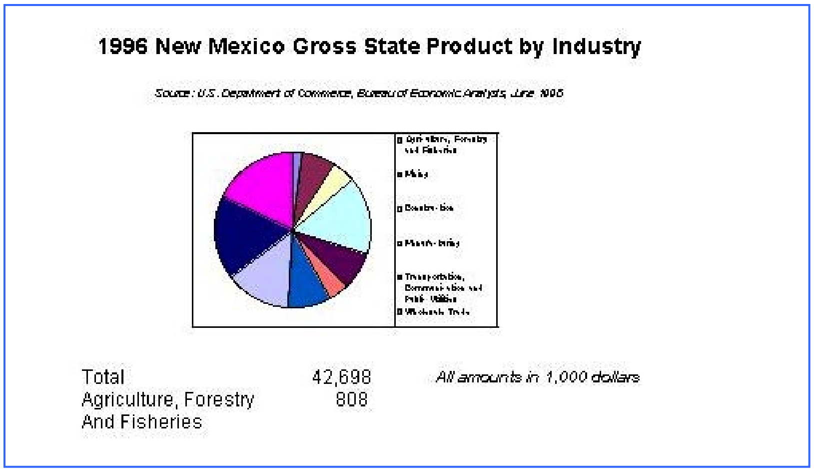

Figure 10

Three Bureau of Reclamation projects furnish most of the water for agriculture in the region. The Rio Grande Project furnishes a full irrigation water supply for about 178,000 acres (71,200 ha) of land, and electric power for communities and industries in south-central New Mexico and west Texas. Drainage water from project lands provides a supplemental supply for about 18,000 acres (7,200 ha) in Hudspeth County, Texas. Project lands occupy the river bottom land of the Rio Grande Valley. About 57% of the lands receiving water are in New Mexico; 43% are in Texas. Physical features of the project include Elephant Butte and Caballo Dams, 5 diversion dams, 139 miles (222 km) of canals, 457 miles (731 km) of laterals, 465 miles (744 km) of drains, and a hydroelectric powerplant.

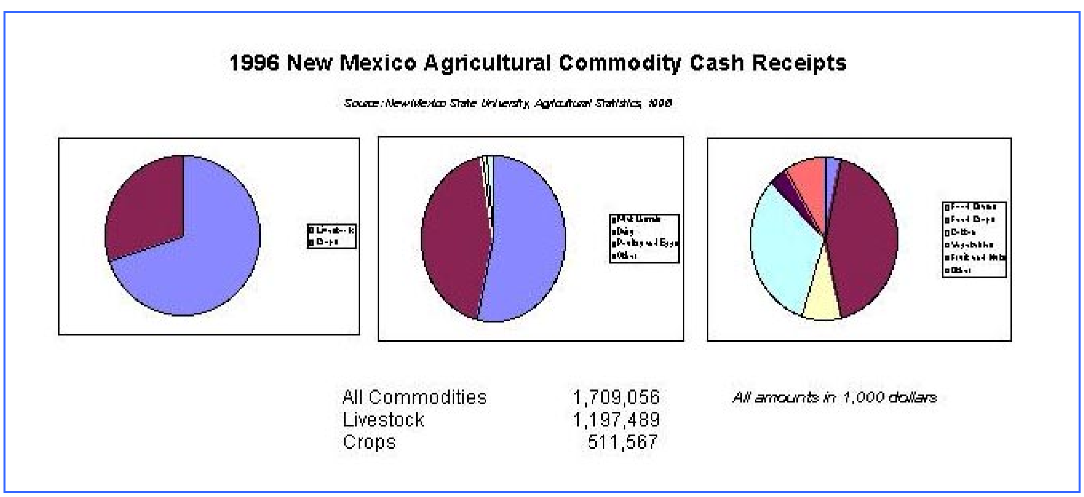

Figure 11

The Middle Rio Grande Project was authorized by Congress to improve and stabilize the economy of the Middle Rio Grande Valley by rehabilitating Middle Rio Grande

Conservancy District facilities and by controlling sedimentation and flooding in the Rio Grande. The Bureau of Reclamation and the Corps of Engineers jointly planned the comprehensive development of the project. Reclamation undertook rehabilitation of El Vado Dam, rehabilitation of project irrigation and drainage works, and channel realignment. The Corps of Engineers was assigned construction of flood control reservoirs and levees for flood protection. The Reclamation project extends along the Middle Rio Grande Valley from the Colorado-New Mexico boundary south to the backwaters of Elephant Butte Reservoir. It includes realignment of the Rio Grande in the vicinity of Truth or Consequences, New Mexico. Built originally by the conservancy district, the irrigation features of the project divert water from the river to irrigate 89,652 acres (35,861 ha) of irrigable land. There are 21,664 acres (8665 ha) of Indian water right lands within the project.

In addition to El Vado Dam, Reclamation rehabilitated Angostura, Isleta, and San Acacia Diversion Dams. El Vado Reservoir provides supplemental storage for the project. Diversions into the district irrigation system are made at Cochiti Dam and at Angostura, Isleta, and San Acacia Diversion Dams. A permanent low-flow conveyance channel was constructed and is maintained as a drain between San Acacia Diversion Dam and the Narrows of Elephant Butte Reservoir to save water to help meet commitments of the Rio Grande Compact. River channelization north of San Acacia Diversion Dam to Velarde, New Mexico also is part of the river maintenance program.

The San Luis Valley Project is in the south-central portion of Colorado near the headwaters of the Rio Grande. The authorized project includes Platoro Dam of the Conejos Division, which regulates the water supply for 80,600 acres (32,264 ha) of land irrigated in the Conejos Water Conservancy District, and the Closed Basin Division, which will salvage shallow ground water now being lost to evapo-transpiration in the Closed Basin of San Luis Valley. The water will be delivered to the Rio Grande for beneficial use in accordance with the Rio Grande Compact and the Treaty of 1906. A small amount of water will be made available to the Alamosa National Wildlife Refuge. The Conejos Division included the construction of Platoro Dam and Reservoir, which was completed in 1951.

Ecology

Changes in environmental policies may affect water deliveries under the Rio Grande Compact. Two major environmental issues are preservation of endangered species, especially the Rio Grande silvery minnow, and preservation of riparian areas. Carriage losses within the river will increase if additional water must be released either to flood riparian woodlands or to maintain minimal year round flows within the streambed for endangered species. The aquatic and riparian ecology of the Upper Rio Grande is extremely disturbed as a result of hydro-modification, irrigation withdrawals, channelization, lack of riparian protection, and pollution

Endangered Species. The historic range of the silvery minnow was from Espanola, New Mexico above Santa Fe to the mouth of the Rio Grande in the Gulf of Mexico. Silvery minnows were also found in the Pecos River, a tributary of the lower Rio Grande. Today, however, the range of the silvery minnow is restricted to a reach of about 170 miles from Elephant Butte Reservoir to Cochiti Dam. In 1994 the U.S. Fish and Wildlife Service determined the silvery minnow to be endangered under the Endangered Species Act. Threats to the species include prolonged flow diversions, channelization and regulation of river flow to provide water for irrigation; diminished water quality caused by municipal, industrial, and agricultural discharges; and competition or predation by introduced non-native fish species. Construction of Cochiti Dam has further restricted minnow habitat by making the river run clearer and colder.

The Fish and Wildlife Service is charged with preserving the silvery minnow by maintaining in-stream flows if necessary. In 1996 the Bureau of Reclamation released water originally contracted by the Fish and Wildlife Service for the Bosque del Apache from storage to provide habitat for the silvery minnow after the Middle Rio Grande Conservancy District diverted the entire flow of the river below its San Acacia diversion dam to agricultural uses. The Fish and Wildlife Service is considering a recommendation to reintroduce the minnow to habitats far removed from the upper Rio Grande, including portions of the Pecos River and along the Big Bend stretch of the Lower Rio Grande in Texas. A requirement to maintain in-stream flow is a new concept in management of the river, and may result in a basic change in the law of the river, by moving the rights of endangered species ahead even of the senior water rights of the Rio Grande pueblos.

Riparian Areas. Western riparian areas and wetlands have great significance as wildlife habitat because of the arid climates in which they are found. Although riparian systems comprise a relatively small percentage of the land area in the Southwest, over 70% of all species inhabiting this region, as well as many transiting migratory species, depend on riparian habitat. Riparian areas slow flood waters; aid in erosion control by protecting shorelines and dissipating the energy of currents; trap sediments; and improve water quality by filtering pollutants from upland sources. Because of the arid climates in which they are located, Western riparian areas frequently have a proportionately greater significance than wetlands and riparian areas elsewhere in the United States. Yet riparian areas in the West often do not qualify technically as wetlands for purposes of regulation under the Clean Water Act.

Estimates are that some riparian areas have declined by as much as 90%to 95% in the West. Surveys of the riparian areas remaining within western public rangelands are incomplete, but thus far the evidence indicates that most are not in healthy, fully functioning condition or are functioning but vulnerable. Riparian areas are affected by diversions from the river channel and by reduced flow. Furthermore, flood control may have interfered with natural processes of inundation that maintained riparian vegetation communities. Conjunctive use of shallow aquifers associated with the stream system can lower water tables and reduce immersion periods required by phreatophytes. Groundwater pumping can affect non-phreatophytes by reducing soil moisture. Riparian communities are also threatened by invasion of exotic plant types like salt-cedars that are associated with disturbance to the water resource. As yet, however, there are no provisions for maintaining in-stream flows or reducing groundwater pumping to preserve riparian areas.

Major riparian areas in the Upper Rio Grande Basin are found along the banks of the Rio Grande; in the Bosque del Apache wetlands near Socorro, New Mexico; along mountain streams; and around some man-made bodies of water. These areas have undergone serious changes since the advent of large-scale irrigation. The Rio Grande, which once meandered through its valley year-round, creating lush stands of cottonwood, now flows only seasonally through pre-set boundaries. In many places, foliage has been cut to allow for a cleaner flow of water. However, man has added new riparian areas with the creation of the same dams and ditches that have affected the river. The effects of all these changes on the plant and animal species have not been evaluated.

The leading factors responsible for riparian wetland degradation include

- Poorly managed livestock grazing.
- Water projects (multipurpose reservoirs, small hydroelectric projects, and small diversions for irrigation).
- Vegetation management (mowing, burning, clearing, or spraying of plants in riparian and upland areas) conducted to maintain floodways, expand pasture and cropland, and help control the Rio Grande in order to maintain a constant border between the United States and Mexico.
- Timber harvesting and associated road building
- Mining and sand and gravel extraction

Federal land management and water resources development agencies – the Bureau of Land Management, the US Forest Service, the Bureau of Reclamation, the Corps of Engineers, the International Boundary and Water Commission, and the Natural Resources Conservation Service -- have not adequately protected riparian areas because of conflicting developmental responsibilities, e.g., grazing, agricultural irrigation, electric power development, flood control protection, and resource extraction.

Municipal and Industrial Water Supply and Wastewater

Since all municipalities along the Upper Rio Grande corridor rely on mining groundwater at unsustainable rates for their current water supply, municipal water management agencies have increasingly emphasized conservation, re-use of waste water and diversion of surface water to municipal and industrial uses.

Albuquerque depends entirely on groundwater for its municipal and industrial supply. The city currently extracts approximately 165,000 acre-feet (204×10^6 m^3) per year from the regional aquifer, while recharge rates are on the order of 65,000 acre-feet (80×10^6 m^3) per year. Albuquerque intends to make up part of its deficit by using its claimed 55,000 acre-feet (68×10^6 m^3) per year of San Juan-Chama Diversion water, by converting native Rio Grande water from agriculture to municipal and industrial use, and by re-cycling municipal and industrial water for irrigation. The New Mexico State Engineer Office, which manages the water resource in the Albuquerque basin, has declared it a "critical basin"; that is, a groundwater basin faced with rapid economic and population growth where there is less than adequate technical information as to the available water supply. Santa Fe relies on groundwater for approximately 75% of its municipal and industrial water. The remaining 25% come from small reservoirs in the Sangre de Cristo mountains north and east of Santa Fe. Santa Fe also has a small claim on San Juan-Chama Diversion water.

The El Paso/Juarez metropolitan area (which includes the city of Las Cruces, New Mexico) lies downstream of Elephant Butte Reservoir. Currently Juarez and Las Cruces take all their water from aquifers, while El Paso obtains 60% of its. Groundwater resources consist of two large aquifers called the Hueco and Mesilla Bolsons. They have been declining and becoming saline at a rapid rate for the last forty years. Groundwater mining for El Paso alone has increased from 95,000 acre-feet (117×10^6 m^3) in 1981 to 124,000 acre-feet (153×10^6 m^3) in 1994. With rainfall in the area averaging around 7 inches (18 cm) per year while groundwater withdrawals increase by 1.8% to 2.5 % per year, rainwater and river water cannot recharge the aquifers fast enough to keep up with demand.

Currently all of Juarez's municipal and industrial water comes from the Hueco Bolson, and Juarez plans to begin pumping the Mesilla Bolson in the near future once a delivery pipeline is complete. Additionally, Mexico is considering treating its 60,000 acre-foot (74×10^6 m^3) Rio Grande allocation for municipal and industrial use and providing irrigators with treated wastewater in exchange. Las Cruces now pumps all of its municipal and industrial water from the Mesilla Bolson, but it too is considering using Rio Grande surface water in the future. This water would also need to be transferred from agricultural use.

A common strategy throughout the corridor is to minimize the use of ground water resources and thus preserve the region's aquifers for drought period use. However, regional population growth may eventually exceed surface allocations. Surface water alternatives for El Paso/Juarez include,

- Increased use of Rio Grande water;
- Construction of regulating reservoirs
- Utilization of surface inflows below Elephant Butte Dam
- Increased water availability created by water conservation through canal lining
- Utilization of unavoidable operational spills
- Utilization of return flows from the Mesilla Valley during the non-irrigation season.

Similar alternatives are being considered by Albuquerque and Santa Fe.

Surface Water Quality. All municipalities in the region face the challenge of treating Rio Grande water, which is highly variable in quality. Suspended solids and turbidity can change dramatically in short periods depending on stream flow and upstream precipitation. Although conventional treatment technologies such as coagulation, flocculation, settling and filtration can effectively reduce solids and turbidity, they cannot remove dissolved contaminants like high concentrations of total dissolved solids (salinity) and total organic carbon. Salinity increases during lower flow periods in the river when a larger portion of the flow tends to be irrigation return flow.

According to the U.S. Environmental Protection Agency, about 28% of New Mexico's surveyed stream miles have good quality water that fully supports aquatic life. Eighty-three percent of the surveyed river miles are safe for swimming. The leading problems in streams include habitat alterations (such as removal of streamside vegetation), siltation, nutrients, and metals. Non-point sources, such as agricultural fields, are responsible for over 96% of the degradation in New Mexico's 3,438 impaired stream miles (5,500 km). Municipal wastewater treatment plants impair about 2% of the degraded waters.

Agriculture and recreational activities are the primary sources of the nutrients, siltation, reduced shoreline vegetation, and bank destabilization observed in 89% of New Mexico's lake acres. Mercury contamination from unknown sources appears in fish caught at 22 reservoirs. However, water and sediment samples from surveyed lakes and reservoirs do not exhibit high concentrations of mercury. Fish may contain high concentrations of mercury in waters with small quantities of mercury because the process of biomagnification concentrates mercury in fish tissue.

Groundwater Quality. The quality of the region's drinking water is generally high. This is due to the aquifers from which water is drawn and the general absence of industrial activities in the area. Arsenic from natural sources is present in the water served in the Albuquerque metropolitan region. While treatment is not required under current federal regulations, the health risks associated with arsenic may eventually lead to more stringent regulation. If that occurs, the city and other nearby villages will have to provide for costly treatment. The most common source of ground water contamination in the basin is small household septic tanks and cesspools. Leaking underground storage tanks, injection wells, landfills, surface impoundments, oil and gas production, mining and milling, dairies, and miscellaneous industrial sources also contaminate ground water.

Water Quality Assessment. New Mexico has a long standing program for the protection of groundwater resources. The program grew from concerns over the environmental effects of oil and gas mining, but now encompasses most major sources of groundwater pollution. New Mexico operates a ground water discharger permit program that includes ground water standards for intentional discharges and a spill cleanup provision for other discharges.

The regulation of hazardous wastes grew from national legislation establishing stringent controls on dangerous chemicals disposed as waste. Waste disposal sites can be remediated under the federal superfund program. Federal laws are often administered by state agencies, with fiscal assistance from the federal government. The federal safe drinking water act is another program administered by the state for the federal government that attempts to ensure water served to consumers is of high quality.

Discharges to surface water are also regulated by the state and federal government. Most direct discharges are from publicly owned sewage treatment facilities. Effluent limitations on these facilities are based on national standards and the needs of the receiving waters. Indirect discharges by industries to sewage treatment facilities are nominally subject to state regulation: in fact, there is little oversight of them. States have changed to secondary treatment for all publicly owned sewage treatment facilities in the last few decades, aided by substantial federal funding.

New Mexico relies heavily on chemical and physical data to assess surface water quality. Fish tissue data became available in 1991, and data from biological surveys and bioassay tests are incorporated into surface water assessments where possible. Extensive monitoring is used to determine the effectiveness of best management practices implemented under the Non-point Source Management Program. Most of New Mexico’s reaches are classified as impaired by the state’s Environment Department. The US Geological Survey maintains a publicly available database of water quality and quantity

Floods and Drought

The Upper Rio Grande Basin lies on the boundary between the Gulf of Mexico and Pacific rainfall provinces. The greatest flood-producing storms have occurred in the transitional seasons, March through May and September through October, when greater temperature differences between air masses moving simultaneously into the region cause increased instability. Historically, floods on the Rio Grande and its tributaries were a fact of life. As increased settlement occurred in the early 1900s, agricultural development in the flood plain was plagued by the build-up of salts in the soil as well as reoccurring floods. The Middle Rio Grande Conservancy District served as the local sponsor for the Bureau of Reclamation to assist with the construction of levees for flood protection and drainage ditches to allow the salts to be flushed from the agricultural fields.

Levees alone could not protect the valley from flooding. In the spring of 1941, the Rio Grande flooded almost nonstop for two months. The flooding prompted Congress to authorize the Flood Control Act of 1941, which directed the Chief of Engineers of the U.S. Army Corps of Engineers to conduct a preliminary study of the Rio Grande Basin. This act was also the basis for a comprehensive plan which developed as a result of coordinated studies by the Bureau of Reclamation and the Corps of Engineers in 1947. The proposed plan was designed not only to prevent the usual types of flood damage encountered in river valleys but also to prevent further deterioration of the agricultural and urban properties of the valley as a result of river-bed aggradation and to return the existing irrigation project to maximum productivity.

Flood Control. The Flood Control Act of 1941 authorized several projects including Jemez Canyon Dam, Abiquiu Dam, and flood protection for the Middle Rio Grande valley. Cochiti and Galisteo Reservoirs were authorized in 1960.

Jemez Canyon Dam was constructed on the Jemez River two miles above its confluence with the Rio Grande. It was completed and placed in operation in 1953. The purpose of the project is to provide flood protection for the Middle Rio Grande Valley from flood runoff originating in the Jemez River Basin.

Abiquiu Dam was completed and placed in operation in 1963. It is a multipurpose project located on the Rio Chama, approximately 32 miles (51 km) upstream from the confluence of the Rio Grande. Abiquiu Reservoir is operated to control flooding on the Rio Chama as well as on the mainstem of the Rio Grande.

Galisteo Dam was completed in 1970. It is located on Galisteo Creek, 12 miles (19 km) above its confluence with the Rio Grande. The purpose of the project is to provide flood and sediment control.

Cochiti Dam was completed in 1975 and is the only flood control reservoir on the mainstem of the Rio Grande designed to regulate snowmelt runoff. The project is approximately 50 miles (80 km) north of Albuquerque, New Mexico. It is a multipurpose dam that functions to regulate damaging flood flows; retain sediment; and develop opportunities for recreation and fisheries development within the pool of water acquired from the Colorado River system via the San Juan-Chama project.

These dams have effectively controlled floods originating in the upper Rio Grande Basin. Sediment retention in these projects has changed a riverbed that was once aggrading to one that is now degrading. However, the degrading river channel is now of concern since nourishing overbank flows that often flooded the riparian community are now much harder to provide.

Drought. Periods of drought are inevitable in the deserts of the southwestern U.S. The Rio Grande Basin is no exception. In recent history, the drought of the mid-1950's was the longest and most severe. Historically, the Bureau of Reclamation has performed most of the Federal drought management functions on the Rio Grande commencing with completion of Elephant Butte Dam in 1916. This reservoir was built to provide a more dependable water supply for agriculture in the lower Rio Grande Basin and to comply with the commitments of the 1906 Treaty with Mexico.

The Middle Rio Grande Conservancy District built El Vado Dam in 1935 to provide conservation storage for irrigation use on the Middle Rio Grande Conservancy District lands along the Rio Grande from Cochiti Dam to below Socorro, New Mexico. It was refurbished in 1953 as part of the Middle Rio Grande Project mentioned above.

The construction by the Bureau of Reclamation of the San Juan-Chama project made possible an average annual diversion of approximately 96,000 acre-feet (118 x 10^6 m^3) from the upper tributaries of the San Juan River in the Upper Colorado River Basin. The water is brought through the continental divide and into the Rio Grande Basin in New Mexico and is used primarily for a municipal and industrial water supply. The imported water is stored and held for release in Heron Reservoir. Heron Reservoir was completed in 1971 and is located on Willow creek just above the confluence with the Rio Chama.

The construction of these reservoirs afforded water users in the Rio Grande a certain degree of protection against droughts. However, the San Juan-Chama project, with terminal storage in Heron Reservoir, is the only facility in the basin that can sustain a reliable water supply through a drought similar to that which was observed in the mid-1950's. El Vado, for instance, can only provide drought protection for about one year.

Technical and Scientific Tools for Better Management

The challenge of managing the waters resources of the Upper Rio Grande Basin is magnified by the complexity of the system. Decisions in one area can have unexpected consequences in others. Science and technology can promote informed decision-making by increasing the data available to decision-makers and by providing computer modeling tools that allow decision-makers to

- Understand links among components of the water resources system
- Experiment with alternative management treatments and strategies
- Predict the consequences of land use changes and global climate variability.

The relatively new science of decision-support systems can help policy-makers integrate socio-economic data with scientific data to assess consequences and perhaps even to optimize decisions (Figure 12).

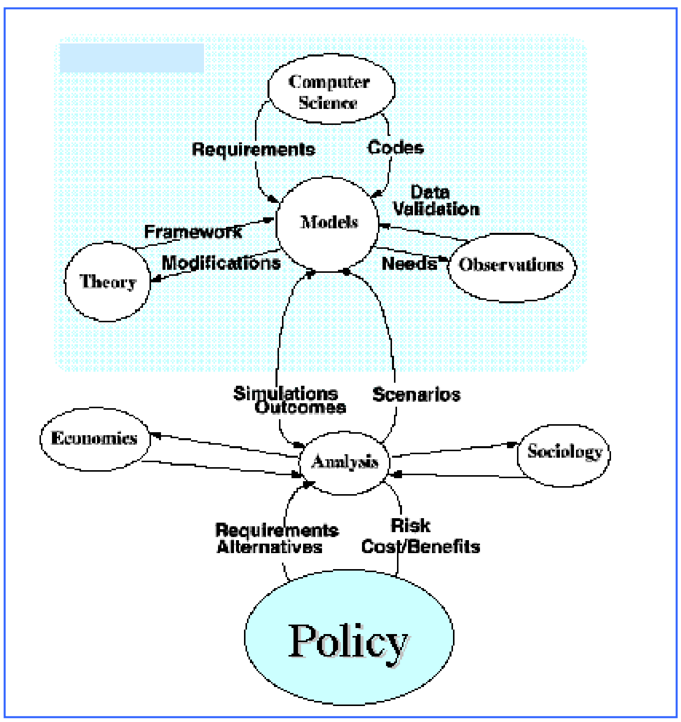

Figure 12. Science and Decision Support Systems in Policy-Making

Data: Measurement and Observation. Assessment and evaluation of the current state of large regions like the Upper Rio Grande has been improved through 1) enhanced measurement and observation capabilities, and 2) new data management and analysis capabilities, especially geographic information systems. Remote sensing systems generally sample various frequencies of the electro-magnetic spectrum, and signal processing converts frequency band data into geophysical variables. Satellite-based remote sensing can provide detailed data on the spatial distribution and variability of such variables as vegetation indices, surface material type and soil moisture. The number of frequency bands sampled, the area sampled, the return rate and the resolution of image elements are the most important features of the instruments themselves. At the same time, highly localized remote sensing like Lidar, a light-based radar, can provide unprecedented resolutions (< 3 m) of the spatial variability of boundary layer quantities like evapo-transpiration over volumes on the order of 1 km^3. The National Science Foundation and the US Department of Agriculture have established sites for long-term monitoring of the water resources and the ecology of semi-arid regions. Although such sites are necessarily localized, they are chosen to be typical and observations obtained from them can be extended to the Upper Rio Grande Basin

Satellite-based Systems. Landsat and SPOT capabilities are well-known. In addition, synthetic aperture radar systems like the Shuttle Imaging Radar-C, the European Space Agency's ERS-1 satellite and the Japanese JERS-1 promise to provide spatially distributed moisture data for the top few centimeters near the soil surface. Data from advanced microwave sensors like the Special Sensor Microwave Imager and the Scanning Multichannel Microwave Radiometer can be used to derive such geophysical parameters as precipitation, cloud liquid water, integrated water vapor, soil moisture, land surface temperature, area covered by snow, and snow water equivalent. The Advanced Very High-Resolution Radiometer and the Airborne Visible and Infrared Imaging Spectrometer provide vegetation data including indices and vitality.

The next generation of NASA's Earth Science Enterprise includes three instruments that will extend current microwave capabilities: the Moderate Resolution Imaging Spectrometer (MODIS), Landsat 7, and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). These instruments are multispectral imagers, which measure electromagnetic radiation in the visible, near- infrared and thermal-infrared parts of the spectrum. MODIS is a moderate resolution multispectral imager designed to measure biological and physical processes globally. It will collect information on surface temperature, concentration of chlorophyll, vegetative conditions -- including leaf area index, cloud cover and cloud properties, and fire occurrence, size, and temperature. In contrast to MODIS, both Landsat 7 and ASTER are high-resolution multispectral imagers. Data from these instruments will generally resemble the high-resolution data already available from Landsats 4 and 5, France's SPOT, and India's IRS-1 satellites. In addition to MODIS and ASTER, the Multi-Angle Imaging Spectroradiometer will gather significant information related to vegetation, land cover type, and soils

Lidar Remote Sensing. Lidar, or light-based radar, can map atmospheric water vapor content in volumes of space at very high resolutions. Lidar has been used to map spatially continuous water vapor flux over riparian woodland sites along the Rio Grande and in southern Arizona. These sites are non-homogeneous and complex. This type of data presents watershed managers with a tool to quantify the water budgets of riparian plant communities with spatial resolution and flux accuracy that is compatible with the new generation of high-resolution basin simulation tools discussed below.

Evapo-transpiration fluxes from riparian communities are difficult to measure because they vary from one point to the next. Although arrays of a few heavily instrumented meteorological towers have been used to estimate the spatial distribution of evapo-transpiration fluxes, tower measurements are intrinsically restricted to a single point and must be interpolated to yield spatial distributions. A scanning, volume-imaging Raman lidar was used in August of 1997 to map the water vapor and latent energy flux fields over the San Pedro waterhed in southern Arizona in order to support the Semi Arid Land Surface Atmosphere (SALSA) program. The SALSA experiment was designed to quantify evapo-transpiration over a cottonwood riparian corridor and the adjacent mesquite-grass community. The lidar showed turbulent convective structures from water vapor images with a resolution of 1.5 m, and mapped fluxes with 25 m spatial resolution (Figure 13). Lidar estimates were validated from sap flow flux estimates of transpiration, and statistical analysis indicates excellent agreement.

NSF LTER. The National Science Foundation established a program in 1980 to support long-term ecological research (LTER) in the United States. The network of LTER sites now consists of 21 project locations representing diverse ecosystems and research emphases. Two LTER sites in New Mexico and a third in Arizona are relevant to the hydrology of the Upper Rio Grande Basin.

The Sevilleta National Wildlife Refuge LTER site is in the Rio Grande Basin south of Albuquerque. Studies there focus on semiarid watershed ecology, especially the evaluation of riparian communities. The site is highly diverse. The main communities represented are: Multiple-intersection of subalpine mixed-conifer forest/meadow, riparian cottonwood forest, dry mountainland, grassland, cold desert, hot desert; conifer savanna; creosote bush; desert grassland; mesquite and sand dunes; Great Basin shrub and shortgrass steppes; tallgrass swales; riparian communities.

Sevilleta LTER topics of special importance to the water resources of the upper basin include

- Semiarid watershed ecology
- Landscape and organism population dynamics in a biome tension zone
- Climate change
- Biospheric/atmospheric interactions
- Control of landscape heterogeneity
- Scale effects on spatial and temporal variability.

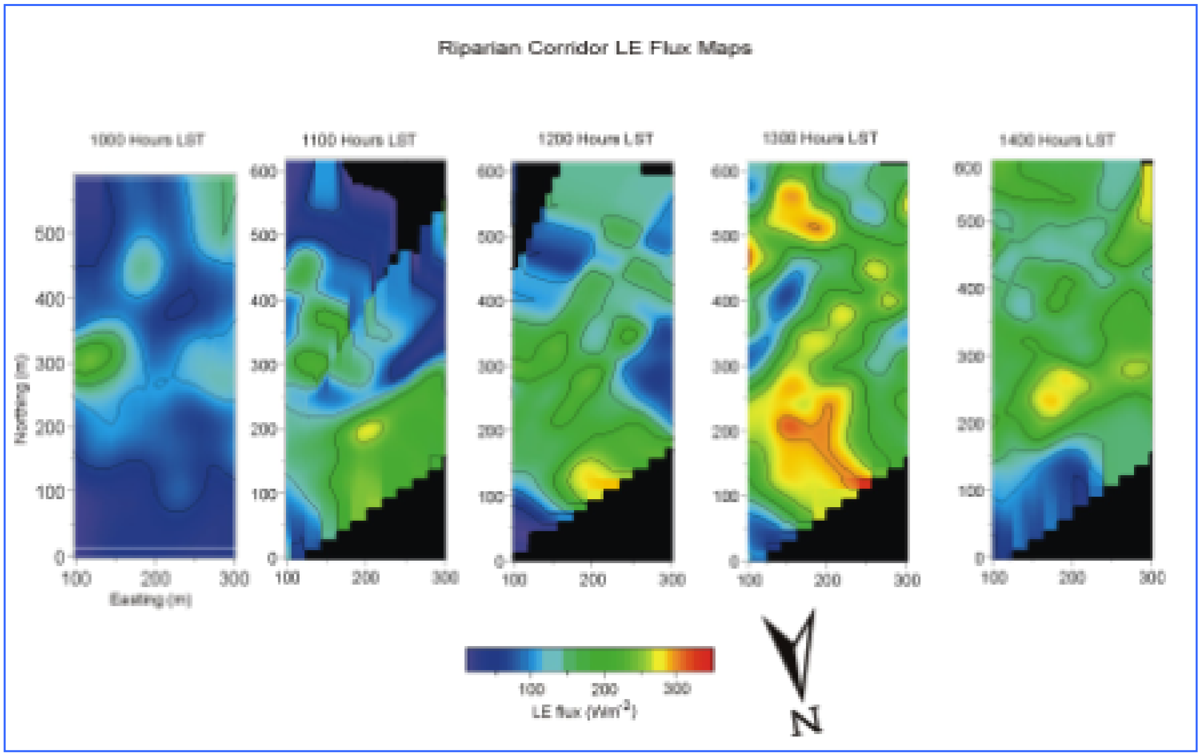

Figure 13. Lidar Observed Evapo-Transpiration Fluxes

The Jornada Experimental Range LTER is in southern New Mexico, east of the Upper Rio Grande Basin. Research at the Jornada site focuses on desertification and surface hydrology among other topics. Principal communities represented are hot desert; playa, piedmont, and swale; bajada, basin, mountain and swale shrubland; and mesquite dunes. The Phoenix, Arizona LTER concentrates on interactions of ecological and socio-economic systems in an urban environment; influence of land use change on ecological patterns and processes; movement of nutrients through highly manipulated flowpaths; interactions of introduced and native species in an urban environment; millenium- and century- geomorphic change in landforms and interaction with engineered landscapes. Its principal biome/main communities are Sonoran Desert scrub; urban parks; residential, interior remnant desert patches; commercial and industrial patches; urban fringe; regulated river and floodplain of a dry effluent-dominated river.

USDA Experimental Watershed. The Walnut Gulch Experimental Watershed consists of 29 nested watersheds ranging in drainage area from 0.002 to 150 km^2. Rainfall and runoff intrumentation (including 85 recording raingauges) has been in place since 1964. Eleven of the nested watersheds are gauged for runoff with concrete supercritical flumes that are specifically designed to give very accurate estimates of runoff. Extensive monitoring of erosion and sediment transport is conducted on eight of the smaller watersheds. The energy balance, soil temperature, soil moisture and CO_2 fluxes are measured at 1) a grass-dominated site and 2) a brush-dominated site. The Walnut Gulch watershed and the containing San Pedro basin are currently the venue for the SALSA program, a multi-disciplinary research effort to observe, quantify and understand the fluxes of water over a wide range of scales within semi-arid watersheds.

Geographic Information Systems. A geographic information system (GIS) is a computer-based tool for mapping and analyzing data and events that have a spatial component. Most data collected for the Upper Rio Grande Basin have a geographic dimension. GIS technology integrates common database technology with the visualization and geographic analysis benefits offered by maps. A GIS stores information about the world as a collection of thematic layers linked together by geography. Unfortunately, no coordinated database exists for the Upper Rio Grande Basin, although each of the basin states has proposed to develop water resources databases. To aid in modeling operations of the Upper Rio Grande, the Upper Rio Grande Water Operations Model (URGWOM, see below) will develop a data base to store the vast amount of data necessary to develop and maintain the model. Likewise, Los Alamos National Laboratory is developing a database to support its regional model.

Modeling and Simulation

Many computational models of different features of the Upper Rio Grande Basin have been developed. The U.S. Geological Survey has, for instance, developed several generations of groundwater models for the Albuquerque Basin, the Espanola Basin and the Mesilla Bolson. We describe the latest version of their Albuquerque model as an example of what can be done in this area. The Bureau of Reclamation and Corps of Engineers have concentrated on models of the operation of the river and reservoir system. Their latest operational model is the Upper Rio Grande Water Operations Model (URGWOM). The advent of high-performance computers has made high resolution models of the dynamic water balance of entire basins feasible. Los Alamos National Laboratory is developing such a model of the Upper Rio Grande Basin.

U.S.G.S. Middle Rio Grande Basin Study. The U.S. Geological Survey Middle Rio Grande Basin Study is a 5 year effort to improve understanding of the hydrology, geology, and land-surface characteristics of the Albuquerque Basin (3,000 mi^2). The aquifer is the principal source of municipal water for the region, and the main purpose of the study is to improve the understanding of the water resources of the basin. Analysis of the basin's hydrology, geology, and land-surface characteristics will provide the scientific information needed for water-resources management in the future. The study began in 1995 and is scheduled to be completed in 2000. The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey began a study of water quality in the Upper Rio Grande Basin in 1991. So far the study has gone through 2 phases: a high-intensity data-collection phase in 1993 and a low-intensity data collection phase in 1996.

URGWOM. The goal of this project is to develop a water model for the Upper Rio Grande to assist water managers in flood control operations, water accounting, and evaluation of water operations alternatives. The Rio Chama segment was selected in 1997 as a test segment for utilization of RiverWare software. In 1996, six federal agencies - the Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, Bureau of Indian Affairs, the International Boundary and Water Commission (U.S. Section), and the U.S. Army Corps of Engineers - recognized the need for a unified water operations model for the Upper Rio Grande Basin and entered into a Memorandum of Understanding to develop such a tool to assist water managers. Additional entities signing the Memorandum of Understanding in 1997 were the cities of Albuquerque and Santa Fe, Rio Grande Restoration, Sandia and Los Alamos National Laboratories. Many other entities, although not yet signatories, are involved in the effort through technical review and outreach support. The interest of this cooperative effort is to develop a numerical computer model capable of simulating water storage and delivery operations in the Rio Grande from its headwaters to Fort Quitman. The model will be used in flood control operations, water accounting, and evaluating water operations alternatives.

Basin-Scale Model. Los Alamos National Laboratory is developing a high-resolution model of a river basin's water balance that places the basin in its global context. The Upper Rio Grande Basin has been selected as a case study for testing the Los Alamos model. The model consists of four interacting components: a regional atmospheric model that is driven by global climate data, a land surface hydrology model, a groundwater hydrology model and a river routing model (Figure 14).

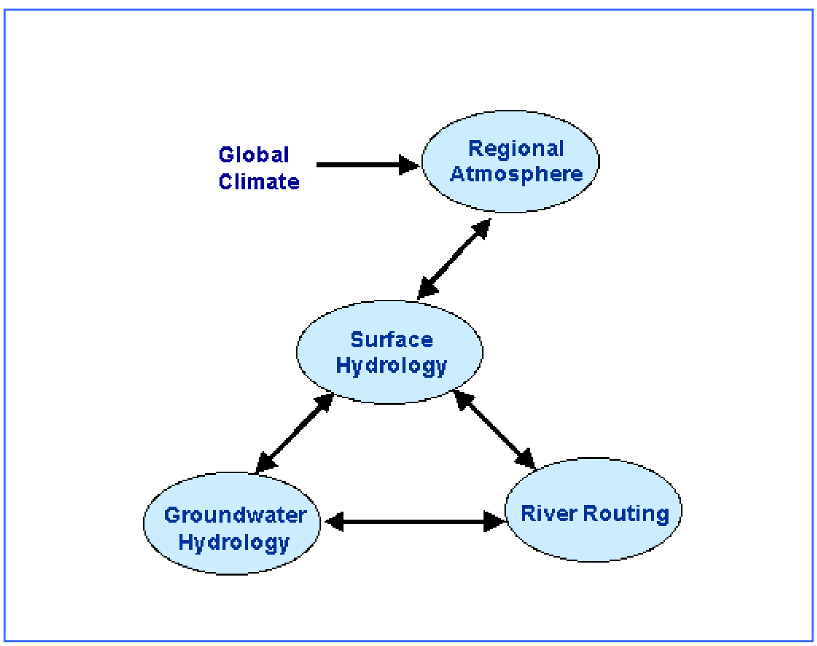

Figure 14. Basin-Scale Model

The regional atmospheric model (currently RAMS, the Regional Atmospheric Modeling System) acts as a down-scaling interface between global and regional climates and provides meteorological variables, especially precipitation, to the land surface model. The surface hydrology model (currently SPLASH, the Simulator for Processes of Landscapes, Surface/Subsurface Hydrology) partitions precipitation into evaporation, transpiration, soil water storage, surface runoff, baseflow, and subsurface recharge. Surface and subsurface runoff are routed through the river channel model, and the groundwater hydrology model (currently FEHM, Finite Element Heat and Mass) is linked to the land surface and channel flow components to simulate saturated and unsaturated flow and changes in groundwater due to natural and anthropogenic effects. The software is designed so that alternative component modules can be substituted for RAMS, SPLASH and FEHM. The system runs on an open partition of the 6,144 processor Blue Mountain supercomputer at Los Alamos.

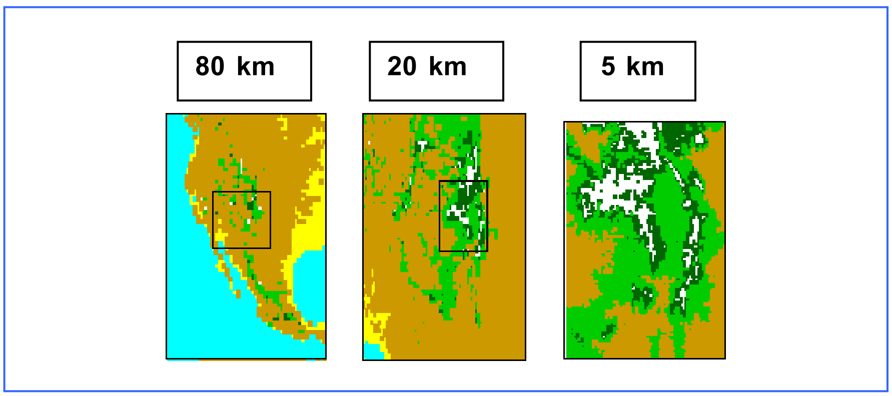

Figure 15. Rio Grande Basin at 3 Resolutions

Coupled models of the regional atmosphere and hydrology are an alternative to the current trend of embedding parameterizations of land surface and subsurface processes in global climate models. A coupled model retains the essential physics of all elements of a water balance and allows feedback between them. Models of regional water balance generally require high resolution because they are meant to support analysis of fine-scaled processes like land-use change, soil moisture distribution, localized groundwater recharge, erosion and flooding. Grid resolutions of 5 km on a side or less seem necessary for atmospheric simulations to represent convective storms that are common in semi-arid regions, while grids of less than 100m are needed for land surface simulations to represent the spatial variability of vegetation and soil classes.

The need for high resolution can be clearly seen in simulations of precipitation and soil moisture. A storm that occurred over the Rio Grande Basin in the winter of 1996 was simulated on the Los Alamos Blue Mountain machine with a parallel version of RAMS using nested 80, 20 and 5 km (on a side) grids. Details of the basin only appear at 5 km resolutions (Figure 15). The importance of these details is clear in the precipitation simulations (Figure 16). Simulations based on 20 km grids do not resolve precipitation in the Sangre de Cristo mountains which cross the border between Colorado and New Mexico in the figure. On the other hand, precipitation over small watersheds can be picked out at 5 km, allowing the effect of the storm on runoff to be estimated at a high level of spatial accuracy.

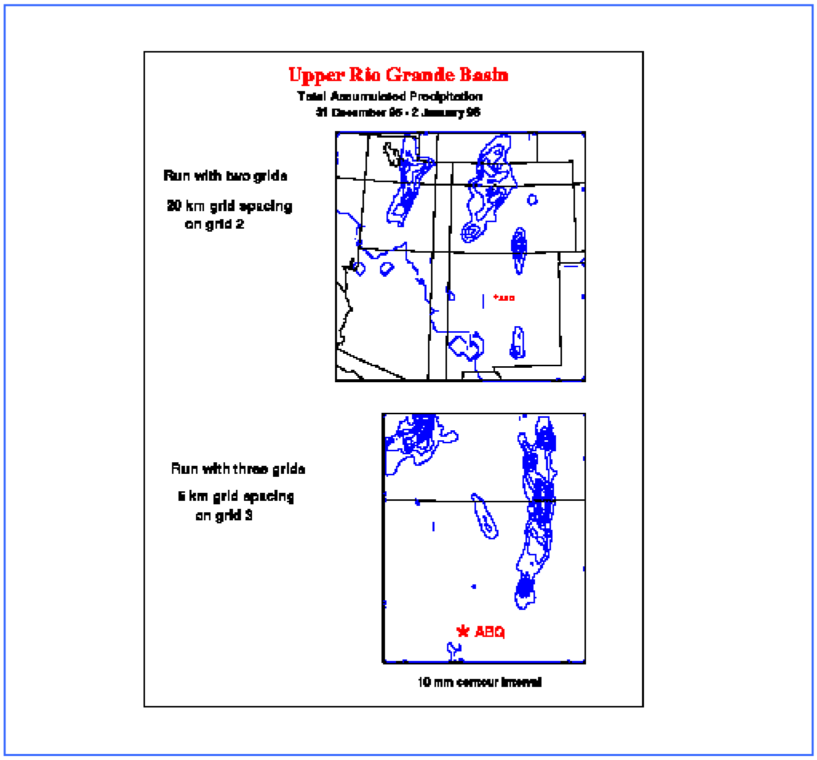

Figure 16. Precipitation Simulations at 2 Resolutions

Recently, regional soil moisture has been simulated by coupling regional precipitation resolved at 5 km to land surface hydrology resolved at 100m (Figure 17). The figure shows simulated soil moisture 12 hours after an event in January 1993. A geo-statistical technique with a deterministic elevation model was used to down-scale simulated precipitation to land surface resolutions (100 m) and then surface hydrology dynamics were used to run precipitation off and infiltrate it into the soil. Although the results shown in the figure are highly preliminary and have not been validated through comparisons with observations, they do indicate the potential of this approach to transform and interpolate climate variables to hydrologically significant data at very high resolutions using dynamical models that fully represent atmospheric and land surface physics.

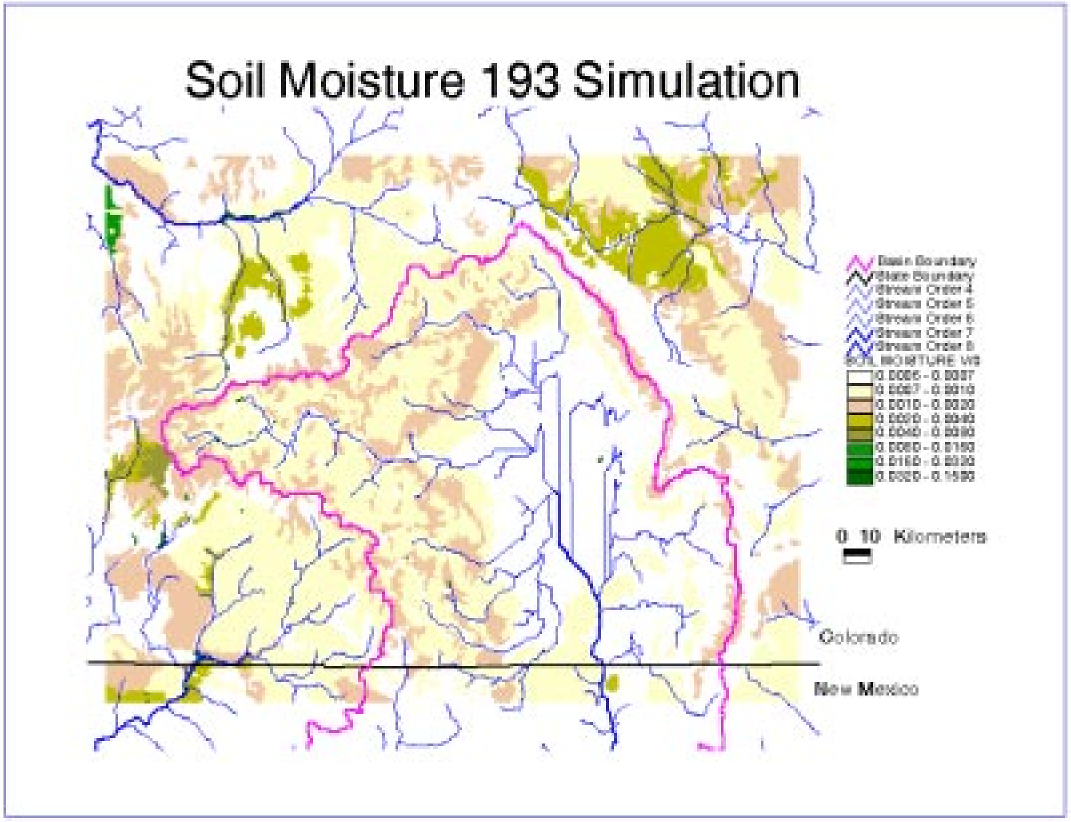

Figure 17. Soil Moisture Simulation (100 m Resolution)

Issues and Principles

The challenge facing the Upper Rio Grande Basin is to implement sustainable practices that will enable it to pass on to the next generations resources that at least equal those this generation has enjoyed. This challenge is indeed daunting given population pressures, the degraded aquatic environment, its declining groundwater resources, and the variations in available water.

Several principles have been applied across the western United States in making the transition to better water management and each of them can be used in this basin.

One. Water management cannot be focused on a single objective, but must include multiple objectives of multiple stakeholders. Most of the institutions that control the Rio Grande's water resources were created when water supply was the domain of engineers and a few political actors. Now, changes in environmental and administrative law and in the political climate demand that all interested parties have a say in water decisions. This means that federal agencies, and to a lesser degree state agencies, are required to hold hearings, prepare environmental review documents, and allow the public to participate in decision making. While there is no broadly based agency in the Upper Rio Grande Basin with legal powers of this sort, such as the Northwest Power Planning Council in the Columbia River Basin, there are new quasi-governmental entities, such as the planning consortium sponsored by the Middle Rio Grande Council of Governments and the New Mexico-Texas Water Commission, that are allowing for widespread citizen participation.

Two. Sustainability is a goal of citizen efforts, and will increasingly be the goal of formal institutions.

Three. Equity must be addressed in water planning. The rights of Native Americans and third party impacts from water transfers must figure in decisions.

Four. Efficiency can assure better decisions about water. Subsidies were provided to agricultural users and hydropower users as the national investment was made in western water. Economic efficiency provides a means of reallocating water within the framework of property rights that is enshrined in appropriative rights water law. This means providing a means of transferring water rights to new uses that are of higher economic value, which provides an incentive for water conservation and directs resources to the most valued uses. Charging users the true costs of water also results in better decision making about a scarce resource.

Many issues arise from these principles

- What agriculture is appropriate? Should government continue to subsidize agricultural use? Who should decide?

- What opportunities exist for further efficiencies in agricultural use? Who should pay for them?

- What are the environmental and land use consequences to losing agricultural development in the basin? What are the social consequences?

- How large should human population in this region grow? While in a democracy citizens are able to choose where they live, government policies can encourage or discourage growth in certain regions. These policies include both state and federal policies. Is information about water resources available to individuals who are making choices about where to live?

- How should the sustainability of natural systems be evaluated? Desert rivers are rare and many have already been irrevocably lost. Should the remaining systems be preserved and restored?

- What information is necessary to manage the resource? How far into the future must we plan? What is the level of uncertainty of predictions?

- What are the likely consequences of demographic, economic and physical change?

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